Technical Report 2012-4

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

ADULT PACIFIC LAMPREY MIGRATION BEHAVIOR AND ESCAPEMENT IN THE BONNEVILLE RESERVOIR AND LOWER COLUMBIA RIVER MONITORED USING THE JUVENILE SALMONID ACOUSTIC TELEMETRY SYSTEM (JSATS), 2011

by

C.J. Noyes, C.C. Caudill, T.S. Clabough, D.C. Joosten, E.L. Johnson,
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Executive Summary

In 2011, we continued our evaluation of the Juvenile Salmon Acoustic Telemetry System (JSATS) for monitoring the migration and final fates of adult Pacific lampreys in Bonneville Reservoir and the Bonneville Dam tailrace, two areas with high unaccounted loss in past telemetry studies. We tagged adult Pacific lamprey (*Entosphenus tridentatus*) with Juvenile Salmon Acoustic Telemetry System (JSATS) tags and half-duplex (HD) PIT tags and monitored their upstream passage and migration behaviors. Our objectives were to calculate lamprey travel times, to estimate escapement past the monitored sites, and to evaluate JSATS detection efficiency.

We tagged 85 adult Pacific lamprey collected at Bonneville Dam with both JSATS and HD-PIT transmitters from 11 June through 3 September. We used two types of JSATS transmitters: a 60 day battery life type and a 400 day battery life type. All fish were trapped and tagged at the Adult Fish Facility at Bonneville Dam and were released at either the Hamilton Island boat ramp (rkm 232) in the Bonneville Dam tailrace or the Stevenson boat ramp (rkm 242.7) in Bonneville Reservoir. We deployed 16 JSATS autonomous receivers between Bonneville and The Dalles Dam tailraces, including one in the Klickitat River 300 m from the mouth. Receivers were deployed singly or in pairs as detection gates allowing us to calculate travel times and determine distribution and final fates for multiple reaches within Bonneville Reservoir.

Estimated detection efficiencies for most of our acoustic receiver gates were 85% or greater, and release site receiver efficiencies ranged from 50% in the Bonneville Dam tailrace to 97% at Stevenson.

The escapement estimate for lampreys released into the Bonneville Dam tailrace past the dam was 35%, lower than estimates from previous HD-PIT studies (41-53%). The escapement estimate from release in Bonneville Reservoir past The Dalles Dam (39%) was similar to that for HD-PIT tagged adults released to the Reservoir and was slightly lower than JSATS-tagged adults from 2010 (43%).

Travel rates for tagged fish were highly variable and were much higher for reservoir than dam and tailrace reaches. Reservoir-released lamprey had a median travel time of 13.6 days (4.8 km/d) from release to The Dalles Dam ladder top. Tailrace-released fish moved rapidly once they passed Bonneville Dam. The median travel time for tailrace-released fish from release to the top of Bonneville Dam was 1.4 days (2.2 km/d), and was 5.8 days (13.8 km/d) from release to the top of The Dalles Dam. Movement through reservoir reaches was rapid (Stevenson to The Dalles Dam tailrace: *median* = 50.5 km/d, n = 26).

Distributions and final fates of tagged fish through early spring were similar to those seen in previous years. The majority (84%) of fish that entered or were released into Bonneville Reservoir passed through the majority of the reservoir and were detected at the Lyle, WA receiver gate, 16 km from The Dalles Dam. This suggests that migration conditions and factors during summer and fall such as predation are not strongly contributing to the overall

unaccounted losses in the Bonneville Reservoir and that fish are not overwintering in the downstream two-thirds of Bonneville Reservoir.

Acoustic monitoring has continued from receiver deployment in mid-May 2011 to date (May 2012). The 400 d battery life transmitters are still active and we anticipate additional data were collected on spring movements of tagged lamprey, if such movements occur. Analyses of data from spring 2012 will focus on tributaries to Bonneville Reservoir. Additionally, we will be testing a prototype acoustic mobile tracking system for monitoring fine-scale habitat usage of tagged lampreys and determining final fates in reservoir and tailrace habitats.

Introduction

Pacific lamprey (*Entophenus tridentatus*) are an ecologically and culturally important native species that has exhibited declines in recent decades (Close et al. 2002; Clemens et al. 2010). In the Columbia River, the adult count at Bonneville Dam in 2010 was the lowest on record (DART 2012). Beginning in 1997, radiotelemetry (RT) studies have examined lamprey passage in the lower Columbia River in an effort to characterize passage behavior and performance. The early focus was at Bonneville Dam (e.g., Moser et al. 2002a, 2002b, 2003, 2005; Clabough et al. 2009; Johnson et al. 2009a, 2009b) and later expanded to include The Dalles, John Day, McNary and Ice Harbor dams (Cummings et al. 2008; Boggs et al. 2008, 2009; Daigle et al. 2008; Keefer et al. 2009b, 2009c). Starting in 2005, half-duplex passive integrated transponder (HD-PIT) transmitters have been used at Columbia and Snake River dams to improve the monitoring of Pacific lamprey movements and distribution in the basin and to complement continuing RT evaluations (Cummings et al. 2008; Daigle et al. 2008; Keefer et al. 2009c, 2012).

Results from both RT and HD-PIT studies have indicated that Pacific lampreys do not readily pass dams and their poor passage efficiency may represent a critical limitation to their migration success (e.g., Moser et al. 2002b; Keefer et al. 2009c). Specifically, Moser et al. (2002a, 2002b, 2003, 2005), Johnson et al. (2009b), and Clabough et al. (2011) found that fishway entrances, collection channel/transition pool areas, count stations, diffuser gratings, and serpentine weirs impede adult Pacific lamprey dam passage at lower Columbia River dams. These data have been used to design, implement, and test a number of passage improvements including Lamprey Passage Structures (LPS, Moser et al. 2011), and modified nighttime operations (Johnson et al. 2009b, 2012). Beyond intensive RT and HD-PIT monitoring at dam fishways and intermittently at the mouths of some tributaries, little information is available on adult Pacific lamprey behavior during migration through tailraces or reservoirs.

Unaccounted-for tagged and untagged lampreys in the Bonneville Reservoir have been a management concern. Lamprey counts at Bonneville and The Dalles dams, limited observations of lamprey spawning or harvest in Bonneville Reservoir tributaries, and RT and HD-PIT results all suggest potential loss of adult lampreys in Bonneville Reservoir. For example, past HD-PIT tag studies found that 38%-67% of adults that passed Bonneville Dam subsequently passed The Dalles Dam, the next upstream monitoring location (Keefer et al. 2012). The difference in adult counts between Bonneville Dam and The Dalles Dam could result from: (1) prespawn mortality of adult migrants in the reservoir or at The Dalles Dam (below the count stations); (2) migration into tributaries of Bonneville Reservoir (e.g., the Klickitat River); and/or (3) systematic over-counting at Bonneville Dam or under-counting at The Dalles Dam.

Unfortunately, the deep bathymetry of Federal Columbia River Power System (FCRPS) reservoirs and the river below Bonneville Dam limits the ability to detect radio transmitters and thereby limits the ability to determine the final fates of tagged lampreys. Acoustic telemetry has several advantages over RT and PIT technologies, including the ability to detect signals in deep water (>10 m). Acoustic transmitters also do not require a trailing antenna which may affect behavior and ultimately survival (Keefer et al. 2009d; Mesa et al. 2011). Until recently, transmitter design and battery size have precluded use of longer-lived acoustic transmitters on smaller species. Because of these limitations, the USACE initiated the development of a new

juvenile salmonids acoustic telemetry system (JSATS; McMichael et al. 2010). The relatively small transmitter size and design of acoustic transmitters for salmonid smolts also make them suitable for other species. In 2010, we performed a pilot study with thirty JSATS-tagged adult Pacific lampreys to evaluate the ability of the technology to monitor adult lamprey using fixed-site and mobile tracking hydrophone receivers (Naughton et al. 2011). The results demonstrated that the technology could be adapted readily to adult lamprey studies in deep water habitats, that mobile tracking could provide useful information on migration behavior and habitat use in reservoirs, and that JSATS monitoring could be used to evaluate passage in some fishway environments. The final distribution of the JSATS-tagged lamprey in 2010 was similar to the final distributions observed in previous radiotelemetry and HD-PIT tag studies (Naughton et al. 2011).

In the 2011 study, we evaluated the use of JSATS for adult Pacific lamprey using a larger sample of tagged fish, ten additional fixed receiver sites, and an additional release location (Bonneville Dam tailrace). Our primary objectives were to characterize lamprey migration behavior and estimate the fate of adult Pacific lamprey in Bonneville Reservoir using the larger array of stationary acoustic JSATS receivers.

We had two secondary objectives that we report briefly here: to evaluate an acoustic mobile tracking device for monitoring the migration and fate of JSATS-tagged adult Pacific lampreys in Bonneville Reservoir; and to evaluate JSATS technology for monitoring adult Pacific lamprey movements in the Cascades Island fishway entrance. We received the mobile tracking unit from the vendor after the 2011 field season, and are currently field testing the system. We plan to incorporate mobile tracking into our 2012 study. Fishway testing at the Cascades Island Fishway occurred during the spill period and hydrophones were deployed in collaboration with PNNL. Testing was limited to short trials because water velocities in and at the entrance of the fishway were too high to keep the hydrophone and test transmitters in place long enough for rigorous testing. Future testing should be conducted using hydrophones and test transmitters mounted on rigid structures, such as the acoustic deterrent device I-beams.

Methods

Fish capture and tagging

Pacific lampreys were captured at night using two traps installed in the Washington-shore fishway that collected fish as they passed over weirs. We also deployed two portable pot traps between the two fixed traps in the fishway. A complete description of the collection and tagging methods is presented in Moser et al. (2002b) and Keefer et al. (2009c, 2012). Collected fish were anesthetized with 60 ppm (3 mL/50 L) clove oil, measured (length and girth to the nearest mm) and weighed (nearest g). Muscle lipid content (% lipid) was collected using a Distell fat meter. Fat meter readings from 2011 were converted to estimated % lipid (wet weight basis) using the regression equation ‘percent lipid’ = 3.618 * reading – 2.436 ($P < 0.01$; $r^2 = 0.4808$; n

= 33). The regression equation was developed by comparing Fatmeter readings taken in 2008 on live lamprey captured at Bonneville (n = 20) and McNary (n = 13) dams to lipid levels determined by biochemical proximate analysis on the same individuals following euthanasia (B. Ho, unpublished data).

Lamprey were surgically implanted with a 4-mm × 32-mm glass-encapsulated HD-PIT transmitter (134.2 kHz; Texas Instruments, Dallas, Texas) and one of two types of JSATS transmitters (Advanced Telemetry Systems, Isanti, MN) modified specifically for use in adult lamprey with additional batteries placed in a flat profile. The first transmitter type was identical to those used in 2010 and had a 60 day rated life (henceforth "60 day tag"). These were 3.0 mm × 5.0 mm × 17 mm, weighed 550 mg in the air, and had an estimated battery life of 60 d with a 5 s burst rate. A second type with a longer 400 day rated life ("400 day tag") was designed based on the 2010 results and became available in the second half of the 2011 study. The 400 day transmitter was 4.0 mm × 8.0 mm × 23.0, weighed 1.7 g in air, and had an estimated battery life of 400 d with a 10 s burst rate. Both the JSAT transmitters and HD-PIT tags were inserted through a small (<1 cm) incision in the body cavity along the ventral midline, in line with the anterior insertion of the first dorsal fin. Incisions were closed with a single suture (3-0 monofilament), and fish were placed in a post-surgery holding tank.

Tagged adults were allowed to recover for at least 2 h post surgery and were released between 11:00 – 16:00 (within 8 h of removal from the trap). Lamprey were released at one of two locations: 1) the Bonneville Dam tailrace, rkm 232.3, or 2) the Stevenson, Washington boat launch, rkm 242.7. The reservoir site was selected as the nearest site to the dam that also minimized the potential for tagged fish fallback over Bonneville Dam, whereas the Hamilton Island tailrace site has been frequently used in radiotelemetry studies (e.g., Clabough et al. 2010; Johnson et al. 2012).

Telemetry monitoring

JSATS-tagged fish were monitored with autonomous receivers provided by USACE (Advanced Telemetry Systems, Trident SR5000) which contain an internal lithium battery pack (rated for 73 d), an externally-mounted hydrophone, water temperature and pressure sensor, and analog and digital circuit boards (McMichael et al. 2010). The receivers were deployed to position the hydrophone about 3 to 4 m above the river or reservoir bottom (Figure 1). The standard deployment configuration consisted of the receiver affixed at a single point to a short section of rope (10 mm, Samson Tenex) or wire cable (3/16 in. stainless steel) with three small floats for additional buoyancy. The receiver was then attached to an acoustic release mechanism (Inter-Ocean Model 111 or Teledyne Model 875-TD; Figure 1). JSATS receivers (n = 16) were deployed starting on 18-May 2011 to form gates across Bonneville Reservoir. Receivers were also deployed in the Klickitat River and Bonneville Dam tailrace. Receivers were deployed by two-person crews in a boat by lowering the system to the bottom. Data obtained from the fixed receivers were used to record final locations, to partition final locations within the reservoir, and to estimate reach travel times of tagged lamprey.

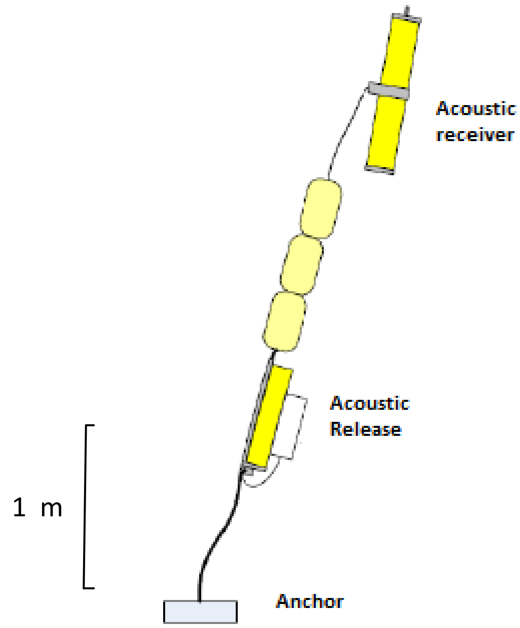

Figure 1. Anchoring and acoustic release system for JSATS autonomous node receivers (image courtesy of B. Smith). The autonomous nodes were deployed approximately 3-4 m off the bottom of the reservoir.

The study area encompassed the lower Columbia and Snake rivers monitored by HD-PIT antennas, but the JSATS portion was focused on the Bonneville Dam tailrace to the tailrace of The Dalles Dam (rkm 304.9) (Figure 2).

JSATS receivers were deployed as gates, singly or in pairs on either the Washington or Oregon shores of the Columbia River, at each of eight locations: one in the Bonneville Dam tailrace (rkm 232); the Bonneville Dam forebay (Washington and Oregon shore, rkm 236.5); Stevenson, Washington (Washington shore, rkm 243.0, Oregon shore, rkm 244.6); Wind Mt. (Washington and Oregon shore, rkm 253.1, mid-river, rkm 253.3); Little White Salmon (LWS) River (Washington shore, rkm 262.3, Oregon shore, rkm 262.4), Bingen, Washington, (Washington and Oregon shore, rkm 275.5); Lyle, Washington (Washington shore, rkm 291.9, Oregon shore, rkm 291.7); The Dalles Dam tailrace, (Washington and Oregon shore, rkm 304.9). One receiver was deployed in the Klickitat River (rkm 290.6) approximately 300 meters upstream from the mouth. Data were also collected on JSATS arrays operated by Pacific Northwest National Laboratory at each of 11 locations: the Bonneville Dam tailrace (rkm 233); Bonneville Dam (rkm 235.1); Bonneville Dam forebay (rkm 236.0); Hood River, Oregon (rkm 275.0); The Dalles Dam tailrace (rkm 307.0); The Dalles Dam (rkm 308.1); The Dalles Dam forebay (rkm 311.0); Celilo, Oregon (rkm 325.0); John Day Dam tailrace (rkm 346.0); John Day Dam (rkm 346.9); John Day forebay (rkm 351.0).

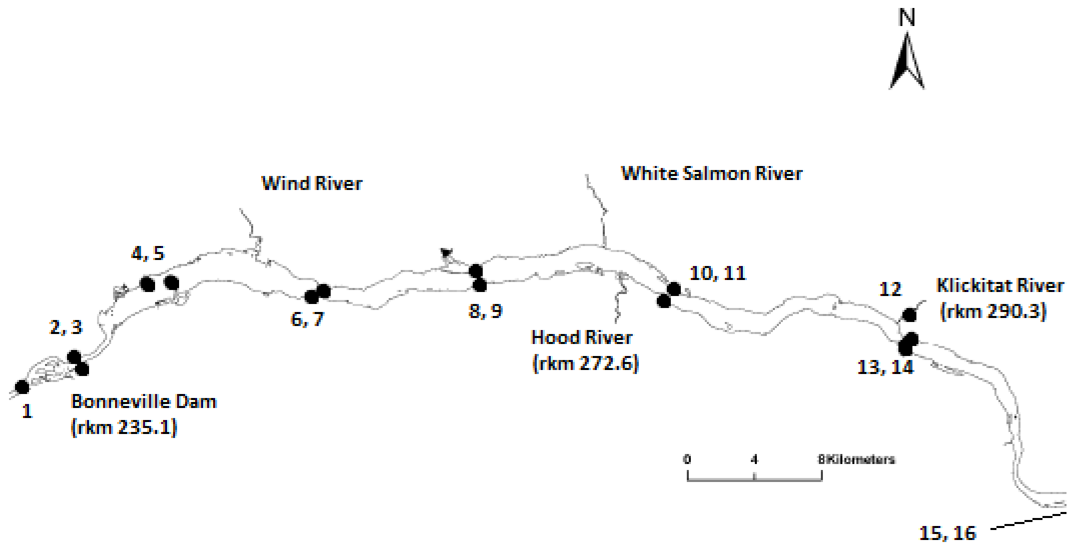

Figure 2. Receiver locations (numbered circles) used to monitor JSATS-tagged adult Pacific lamprey in 2011: 1) Bonneville Dam tailrace, 2, 3) Bonneville Dam forebay, 4, 5) Stevenson, 6, 7) Wind Mt., 8, 9) Little White Salmon R., 10, 11) Bingen, 12) Klickitat R., 13, 14) Lyle, 15, 16) The Dalles Dam tailrace.

Lamprey detections on HD-PIT antennas were also used to monitor passage at Columbia and Snake River dams, and to determine final fates of Pacific lampreys. HD-PIT antennas were located at the tops of fish ladders at Bonneville, The Dalles, John Day, McNary, Priest Rapids, and Wanapum Dams on the Columbia River, and at Ice Harbor and Lower Granite Dams on the Snake River. These sites were maintained by UI (lower Columbia and Snake River dams), and LGL (mid-Columbia River dams). Additional HD-PIT antennas were located in Fifteen Mile Creek, a small tributary that empties into the Columbia River in The Dalles Dam tailrace, and in some Deschutes River tributaries (maintained by the Confederated Tribes of Warms Springs Reservation of Oregon [CTWSRO]).

Data downloading and processing

Data were loaded into a database maintained at the University of Idaho. Autonomous nodes were downloaded monthly by transferring data to a portable computer. Clocks on all receivers and readers were synchronized to assure comparability between data collected between different sites. Records were screened to remove obvious error (noise) records and detections that occurred before fish were released. Records were inspected for accuracy, and assigned codes summarizing the movements of tagged fish. After the study season, we exchanged data with other researchers (e.g., PNNL) using JSATS transmitters and receivers to ensure the most complete migration histories for all JSATS-tagged fish.

Data analysis

Lamprey travel times (d) and migration rates (km/d) were calculated from the last record at a receiver site to the first record at upstream receiver sites. We estimated detection efficiency for each receiver site by comparing detections at the site with all lampreys detected on JSATS receivers and HD-PIT antennas at upstream sites. Detection on individual JSATS receivers required assumptions about valid versus invalid ("noise") detections and we used several criteria to evaluate how different assumptions affected interpretations of lamprey movement behaviors, rates, and final distribution. The base criteria that we used to code data required at least two detections within a thirty minute time block within a plausible spatial range. We also evaluated more conservative criteria by rescoring the final detections as valid if at least two detections were recorded with 1, 2, 5, or 10 minute time blocks, where the probability of recording false positives decreased in shorter time blocks. The criteria used to code detections as valid affected the interpretation of final location for 9 (10.6%) of lampreys. The final locations coded using the base criteria for individual fish were upstream (n = 3), nearby (n = 4), or downstream (n = 2) of locations using more conservative coding criteria. A more complete analysis of the relationship between detection criteria and other passage metrics awaits completion of JSATS filtering software, expected to be released in fall 2102. Thus, we note that values reported here using the base criteria should be considered provisional but conclude that use of other criteria are unlikely to strongly affect the overall interpretation of final fish distributions.

Coded data using the base criteria were used to estimate several passage metrics. We estimated residence times at receiver sites and described the final locations of individual fish using both JSATS and HD-PIT detection records. We tested for associations between lamprey migration rate and tag date, temperature and fork length using univariate regression. All analyses were based on data collected from May 2011 through March 2012.

We compared the passage frequencies of JSATS and HD-PIT only tagged adults to test whether there was evidence of a greater tag burden in the JSATS-tagged adults (recall, adults were double tagged with JSATS + HD-PIT or HD-PIT only) using Chi-square tests. We also ran logistic models that statistically controlled for the potential effects of tag date and weight on passage probability (Keefer et al. 2009c) using the model: Pass (Y, N) = tag type + tag date + mass (g). The latter test has more parameters and lower statistical power and we therefore focused on results of the Chi-square tests given the relatively small sample size.

Results

Lamprey tagging and release

The total number of adult lamprey recorded at Bonneville Dam in 2011 was 51,606 (daytime count = 18,315; night video count = 18,957; LPS count = 14, 334). A sample of 85 lampreys, representing 0.16% of the total count at Bonneville Dam, was double-tagged with JSATS transmitters and HD-PIT tags in approximate proportion to the run (Figure 3). Lamprey were JSATS-tagged with either 60-day (n = 20) or 400-day (n = 65) estimated battery life transmitters. The 400-day tags were used after delivery from the manufacturer in the second portion of the season. Fish were released into either the Bonneville tailrace (n = 23) at Hamilton Island (rkm

232.3), or Bonneville Reservoir (*n* = 62) at Stevenson, WA (rkm 242.7). All lampreys released into the tailrace were tagged with the 400-day tags.

Size metrics and percent lipid were similar between JSATS and HD-PIT-tagged only adults collected and tagged in 2011 (Table 1). Mean surgery time was 8 minutes (*range* = 5 -11).

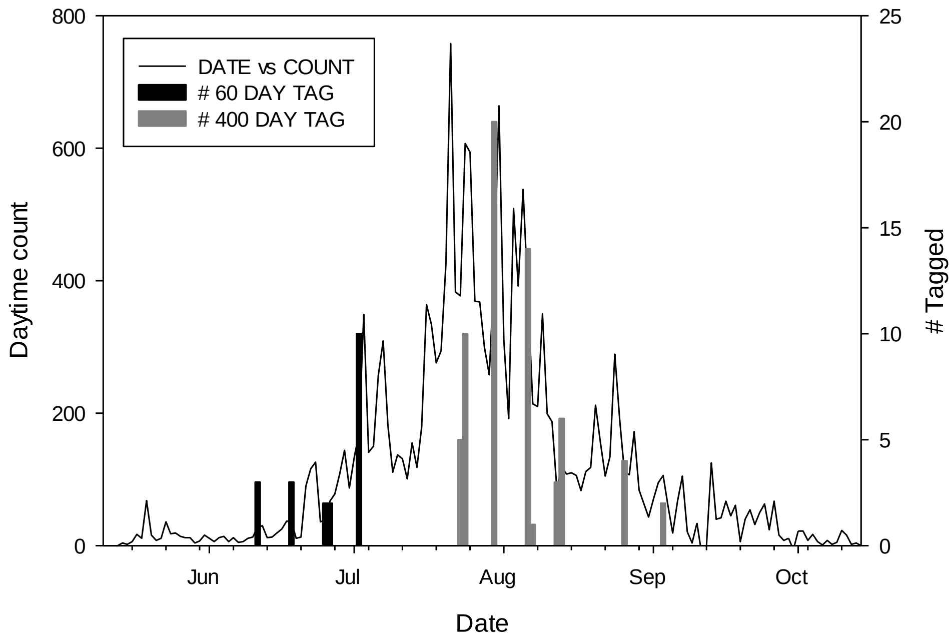

Figure 3. Distribution of JSATS-tagged Pacific lamprey and daily daytime count at Bonneville Dam, 2011.

Table 1. Length, weight, girth, and percent lipid of adult Pacific lamprey double tagged with HD-PIT and JSAT transmitters at Bonneville Dam in 2011. For comparison, data from lampreys that were tagged only with HD-PIT tags in 2011 are shown; details for this study group are reported in Keefer et al. (2012).

	Length (cm)			Girth (cm)			Weight (g)			Percent Lipid (%)		
	n	Mean	*sd*	*n*	Mean	*sd*	*n*	Mean	*sd*	*n*	Mean	*sd*
Tailrace release	23	64.7	4.3	23	10.9	0.6	23	448	68.7	23	21.8	9.3
Stevenson release	62	65.1	4.5	62	10.7	0.9	62	436	89.4	62	21.9	11.0
All fish	85	65.0	4.4	85	10.7	0.8	85	439	84.2	85	21.9	10.5
2011 HD-PIT tagged only	929	64.8	4.1	924	10.8	0.8	856	435	83.7	833	24.6	8.1

Telemetry monitoring

Monitoring in 2011 began with a set of six autonomous nodes which were deployed prior to the release of tagged lampreys (Figure 4). These six nodes were deployed near the 2010 sites (Stevenson [Washington and Oregon shore], Wind Mt. middle, Lyle [Washington and Oregon shore], and Klickitat River sites). The remaining 10 receivers were deployed shortly after receipt from the manufacturer in mid- to late July at mid-reservoir and The Dalles Dam tailrace sites. Coverage at the Wind Mt. site was increased to 2 receivers in July. Due to high river discharge, tailrace receivers were the last to be deployed. Summer access to the Klickitat River site was restricted due to low reservoir levels, and the site was discontinued in August. Coverage at most sites remained in place until January of 2012, and 3 gates remain in place to date. Most sites had nearly continuous coverage, with short (<1 h) periods of no coverage for receiver maintenance, while other sites had some significant gaps in coverage, usually due to battery or electronics failure (Figure 4).

Detection efficiencies differed by location and receiver type. Of the 85 lamprey released, 79 (93%) were detected on at least one autonomous node receiver operated by UI. When we included records on PNNL-operated arrays, the number of fish detected increased to 84 (99%). One fish released in the Bonneville Dam tailrace was never detected on any receiver, perhaps due to a faulty transmitter or movement downstream of the tailrace without detection. Detection efficiency was 43% at the Bonneville Dam tailrace receiver near the release site and 97% at the receiver near the Stevenson, WA release site. Within Bonneville Reservoir, detection efficiencies ranged from 56% at the Bonneville Dam forebay receivers to 96% at the The Dalles Dam tailrace receivers (Figure 5). No tagged lampreys released in the tailrace were observed on the PNNL array downstream at rkm 161.

Most (83%) of adults detected in the Bonneville Reservoir were later detected at upper reservoir sites (Figure 6). The proportion of adults detected at upstream sites differed between release locations because many lamprey released to the tailrace did not pass Bonneville Dam (Figure 6), and because detection efficiencies were generally lower in the wider, deeper downstream sites (compare Figures 5 and 6). The distribution of adults upstream of Bonneville Dam was similar for those released to the tailrace that passed Bonneville Dam and those released at Stevenson, WA (Figure 6).

Within Bonneville Reservoir, the percentage of lampreys detected ranged from 52% at the Wind Mt. site to >90% at both the Bingen, WA and Little White Salmon River sites (Figure 5). Five of the reservoir-released fish were detected on the Klickitat River receiver (8%). One fish was detected downstream of the release site in the Bonneville Dam forebay (2%), and no reservoir released fish were detected below Bonneville Dam. Of the 23 fish released into the Bonneville Dam tailrace, 10 (43%) were detected on the tailrace receiver. When we included records on PNNL operated tailrace arrays, the number of fish detected increased to 20 (87%). Within Bonneville Reservoir, the percentage of lampreys detected for all tailrace-released fish ranged from 17% at the Bonneville Dam forebay site to 35% at the Lyle, WA site (Figure 6). Of the tailrace released fish, 15 (65%) were never detected on any receiver above Bonneville Dam.

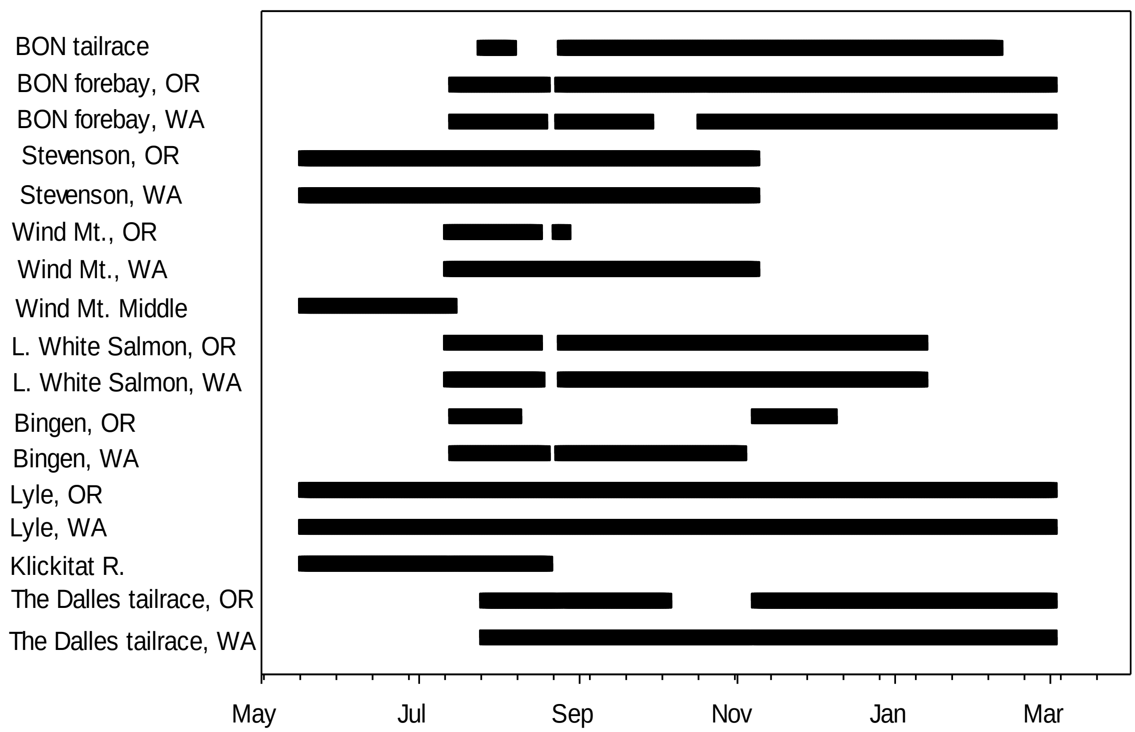

Figure 4. Autonomous node deployment schedule by site, May 2011 to March 2012.

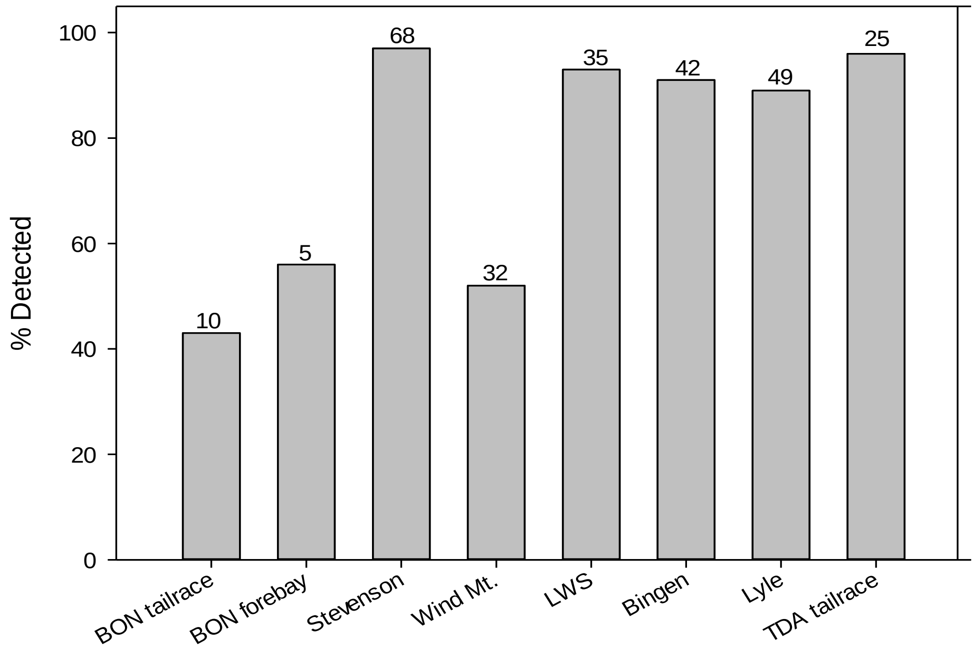

Figure 5. Detection efficiencies of JSATS receivers, by site, for all tagged Pacific lamprey. Sample sizes are shown above each bar.

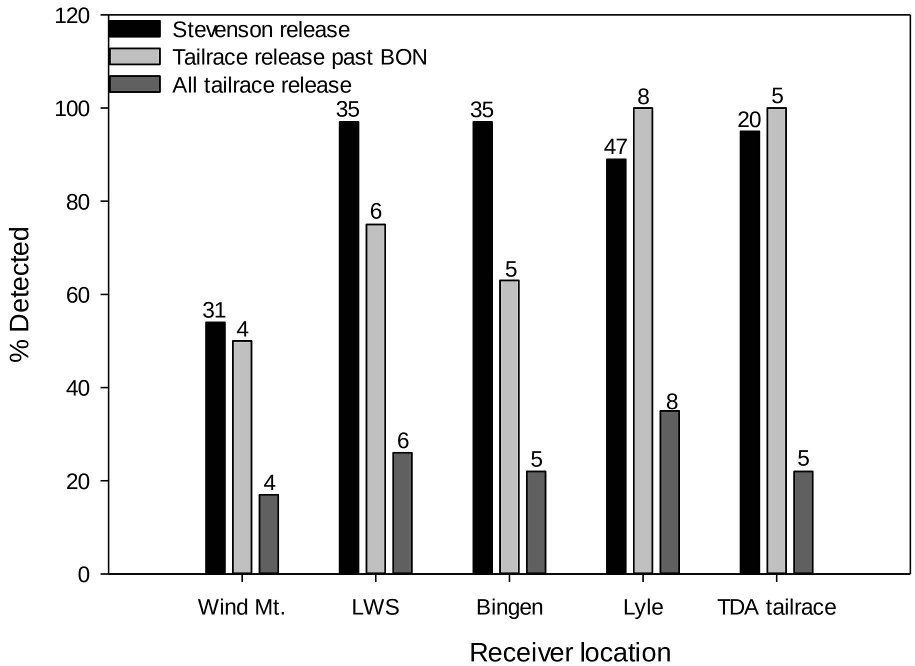

Figure 6. Percentage of JSATS tagged Pacific lamprey detected at Bonneville Reservoir receiver sites, by release group. Sample sizes are shown above each bar.

Diel activity

Records of first and last detections at release site receivers indicated lampreys remained near the release site on the day of release before commencing post-release movement at night. Of the 62 fish released into Bonneville Reservoir, 58 (94%) were first detected at the Stevenson Washington shore receiver. Most (63%) of the first detections were between 18:00 and 23:00 and most (59%) of the last detections were between 22:00 and midnight (Figure 7). Of the 23 fish released into the Bonneville Dam tailrace, 10 (43%) were first detected on the tailrace receiver. Including records on the PNNL tailrace receivers, the number of fish first detected in the tailrace increased to 15 (65%). Most fish (73%) were first detected between 16:00 and midnight. Most (60%) last detections occurred between 20:00 and midnight (Figure 7).

Tagged lampreys moved upstream during daytime and nighttime. First and last detections at mid-reservoir receiver sites showed most movement occurring during early morning to midday at Bingen, and early afternoon at Lyle based on detections of the Stevenson-released lampreys. The first and last detections among the small sample (*n* = 7) of tailrace-released lampreys were more uniform than the Stevenson release group, but this pattern cannot be rigorously evaluated given the sample size. First and last detections for both release groups at The Dalles tailrace sites were more evenly distributed throughout the entire day (Figure 8).

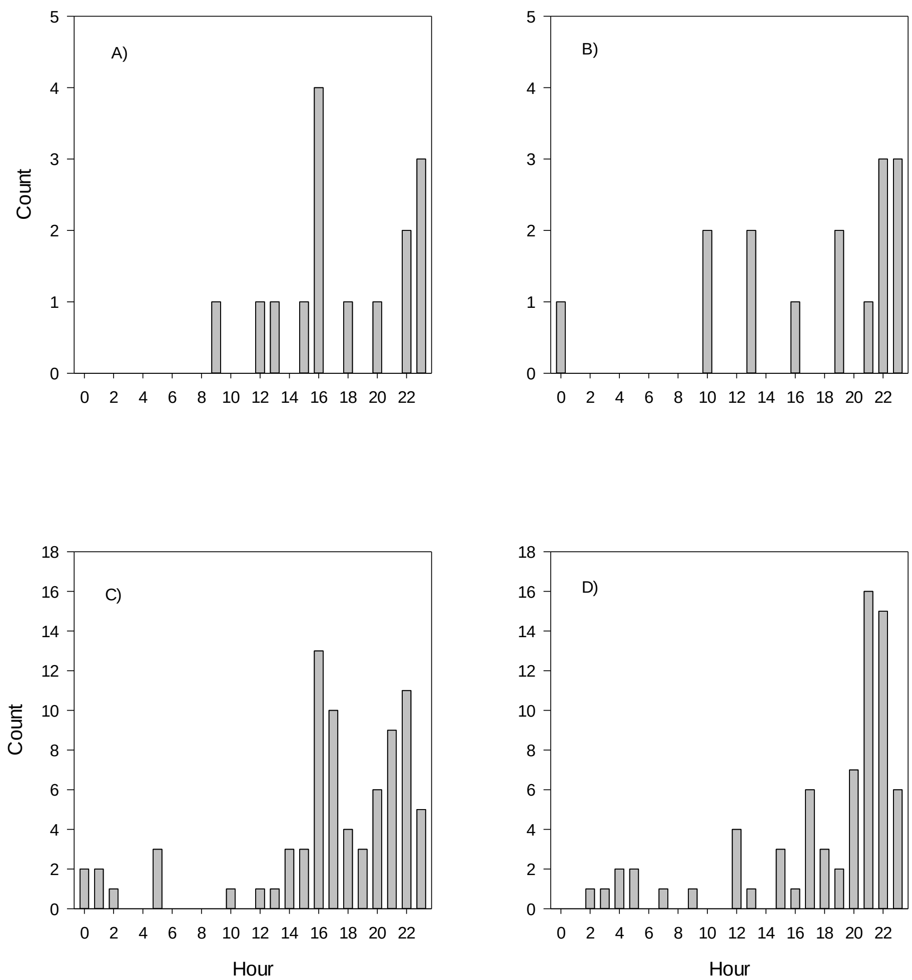

Figure 7. Distribution of first (left) and last (right) detections by hour of JSATS-tagged Pacific lamprey on receivers at the Bonneville Dam tailrace (A and B) and Stevenson (C and D) release sites (Washington and Oregon shores, combined).

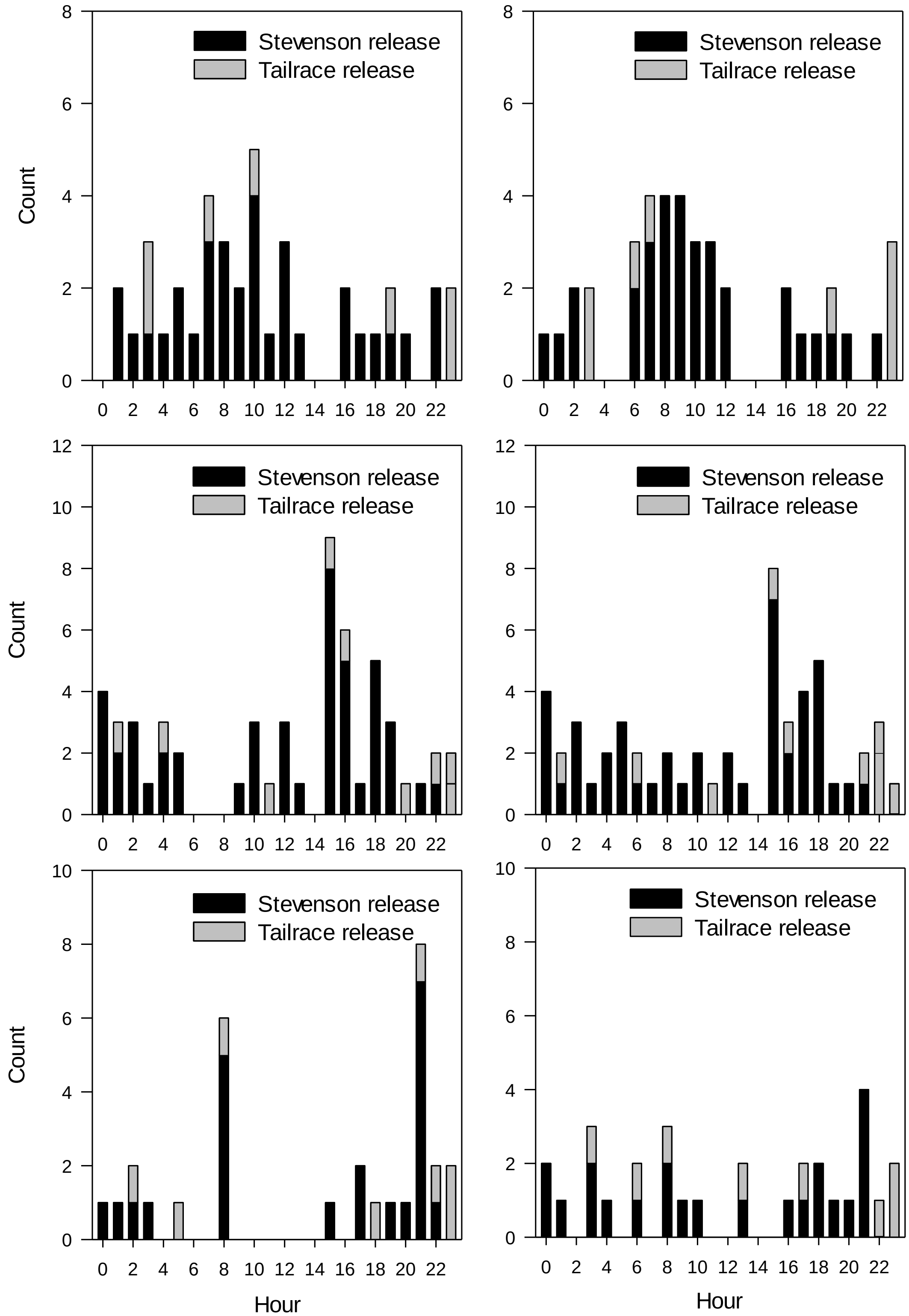

Figure 8. Distribution of first (left) and last (right) detections of JSATS-tagged Pacific lamprey on Bingen (A and B), Lyle (C and D), and The Dalles Dam tailrace (E and F) receivers (Washington and Oregon shores, combined).

Travel times and migration rates

Once movement resumed post-tagging and adults entered the Reservoir, tagged lampreys migrated quickly upstream (Figure 10). Travel times for tailrace-released lampreys from release to upstream sites were longer than for Stevenson-released lampreys because lamprey passed Bonneville Dam relatively slowly (Figures 10). Once in Bonneville Reservoir, travel times for tailrace-released fish decreased and migration rates increased (Figure 9 and 10, and Table 2).

Analyses using univariate linear regression found no significant correlations between migration rate through the reservoir reach with the largest sample size (Little White Salmon River to Lyle) and release date (n = 33, r^2 = 0.089, P = 0.090), fork length (n = 33, r^2 = 0.004, P = 0.742), or water temperature (n = 33, r^2 = 0.054, P = 0.195) (Figure 11).

Table 2. Travel times (d) and migration rates (km/d) of JSATS-tagged adult Pacific lamprey released in the Bonneville Dam tailrace (top) and at Stevenson, WA (bottom), 2011.

		Travel time (d)			Migration rate (km/d)		
Reach	*n*	Mean	Median	Range	Mean	Median	Range
Tailrace-released fish							
Release - BON forebay	4	4	2.5	1.3 - 9.8	2.1	2.2	0.5 - 3.6
Release - TDA tailrace	6	7.3	7.1	2.3 - 13.6	15.3	10.8	5.4 - 32.1
Stevenson - LWS	3	0.5	0.5	0.2 - 0.8	47.3	38.3	23.0 - 80.5
LWS - Lyle	5	0.6	0.5	0.5 - 0.9	52.1	54.2	32.4 - 63.6
Lyle - TDA tailrace	5	0.3	0.3	0.2 - 0.3	50.3	49.1	46.1 - 55.2
Reservoir-released fish							
Release - LWS	35	1.6	0.6	0.4 - 13.5	27.3	30.6	1.4 - 51.0
Release - Lyle	47	3.4	1.4	0.8 - 19.6	28.8	35.4	2.5 - 59.4
Release - TDA tailrace	24	4.1	1.8	1.1 - 24.7	30.8	33.9	2.5 - 56.0
LWS - Lyle	28	0.8	0.6	0.4 - 2.8	47.7	53.3	10.6 - 67.1
Lyle - TDA tailrace	22	1.7	0.3	0.2 - 19.1	39.5	46	0.7 - 64.0

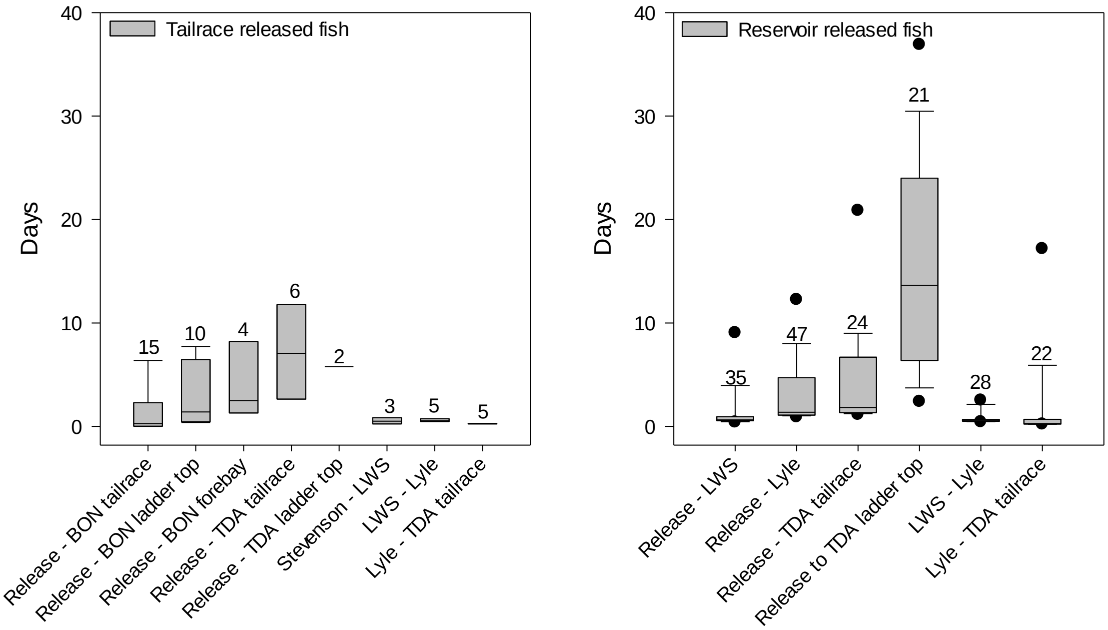

Figure 9. Travel times by reach for JSATS-tagged Pacific lamprey released into the Bonneville Dam tailrace at Hamilton Island (left) or Bonneville Reservoir at Stevenson, WA (right). Sample sizes are shown above each bar. Box plots show 5th, 25th, 50th, 75th and 95th percentiles.

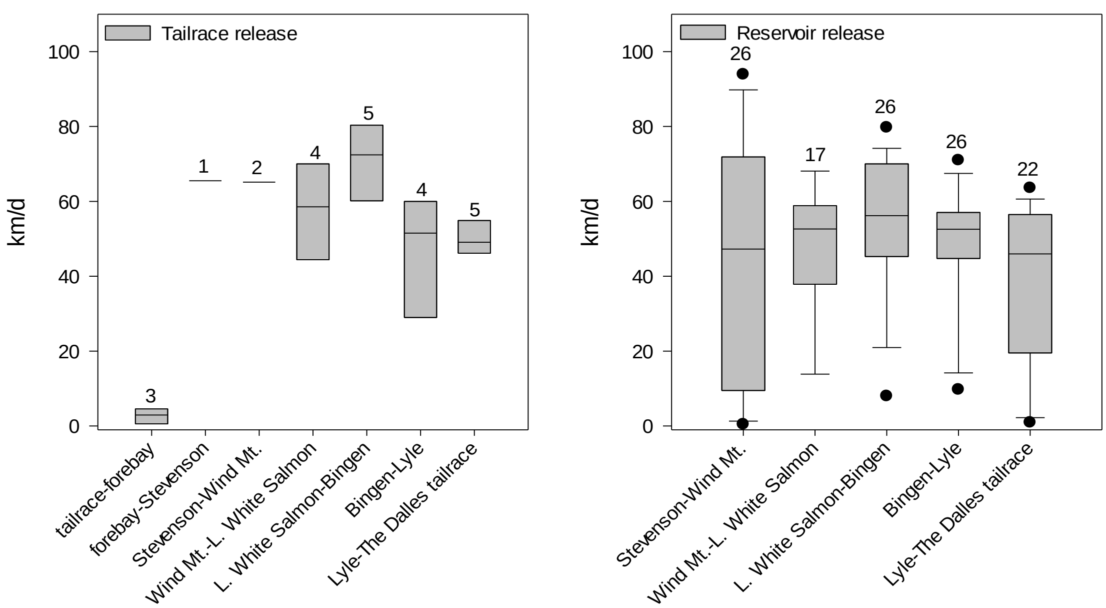

Figure 10. Migration rates (km/d) by reach for JSATS-tagged Pacific lamprey released into the Bonneville Dam tailrace at Hamilton Island (left) or Bonneville Reservoir at Stevenson, WA (right). Sample sizes are shown above each bar. Box plots show 5th, 25th, 50th, 75th and 95th percentiles.

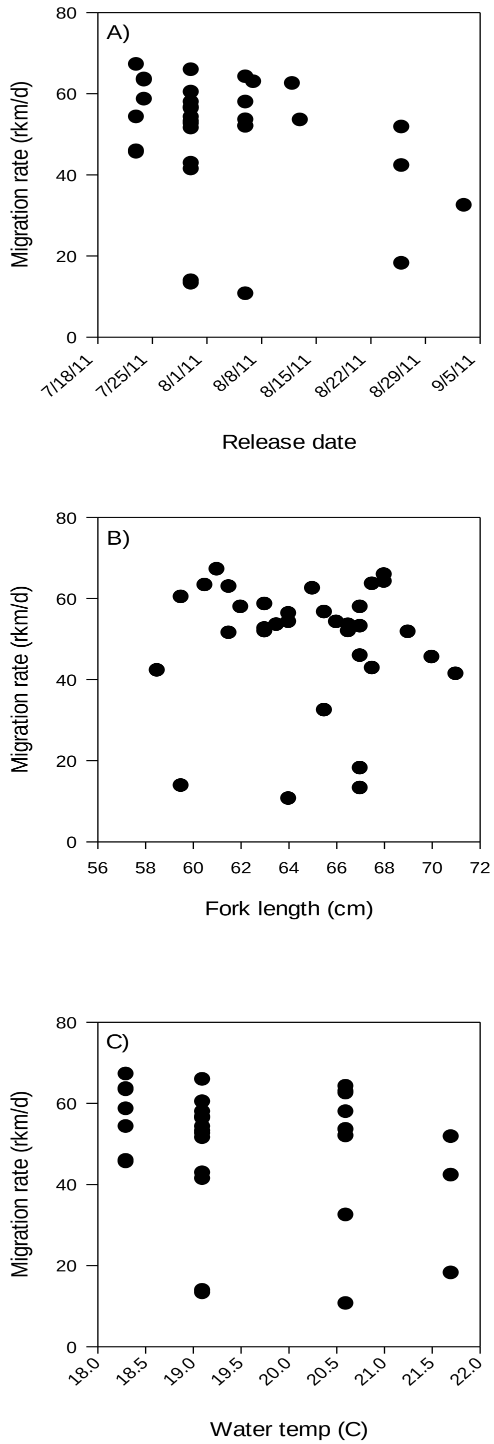

Figure 11. Relationships between migration rate (Little White Salmon River-Lyle reach) and release date (A), fork length (B), and water temperature at release (C) for adult Pacific lamprey tagged in 2011 (both release groups combined).

Residence times

We examined residence time within the detection range of individual autonomous nodes as a secondary measure of migration rate. Lampreys were present near both release sites for the longest periods (minutes to hours), but were present at other sites for fifteen minutes or less in nearly all cases (Figures 12 and 13). High values at the Wind Mt. middle receiver site were likely due to its close proximity to the Stevenson release site. Median residence time at the Bonneville Dam tailrace receiver was 0.4 h (*mean* = 1.0 h; *range* = 0.02 – 4.3 h) (Figure 12). Median residence time at the Stevenson Washington and Oregon shore receivers was 0.5 h (*mean* = 1.0 h; *range* = 0.1 – 4.8 h) and 0.2 h (*mean* = 0.2 h; *range* = 0.002 – 0.9 h), respectively (Figure 12). Mean residence times at other lower reservoir receivers ranged from 0.1 h at the Washington shore forebay site to 0.9 h at the Wind Mt. middle site (Figure 12). Mean residence times at upper reservoir receivers ranged from 0.2 h at the Oregon shore Bingen site to 0.5 h at the Washington shore Lyle site (Figure 13).

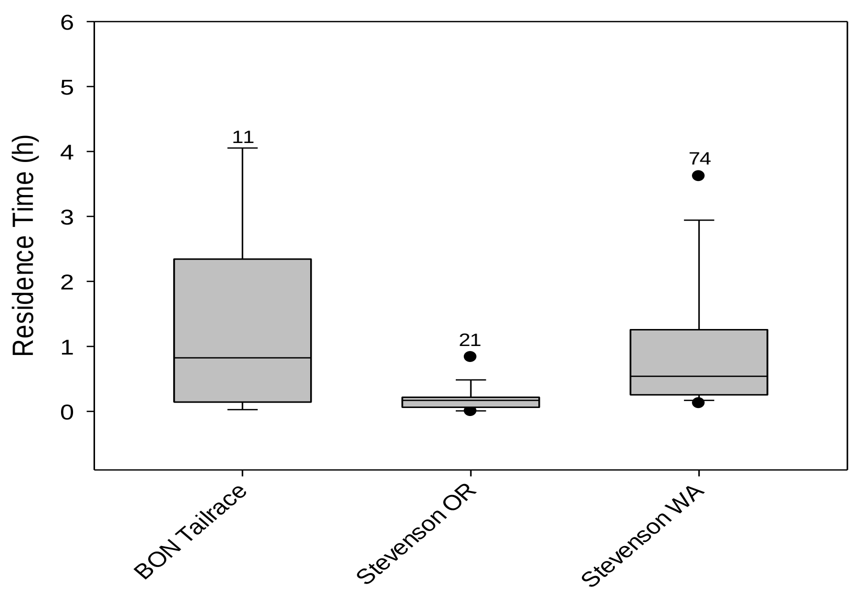

Figure 12. Residence times for JSATS-tagged Pacific lamprey on release site receivers in the Bonneville Dam tailrace, and at Stevenson, WA in Bonneville Reservoir. Sample sizes are shown above each bar. Box plots show 5th, 25th, 50th, 75th and 95th percentiles.

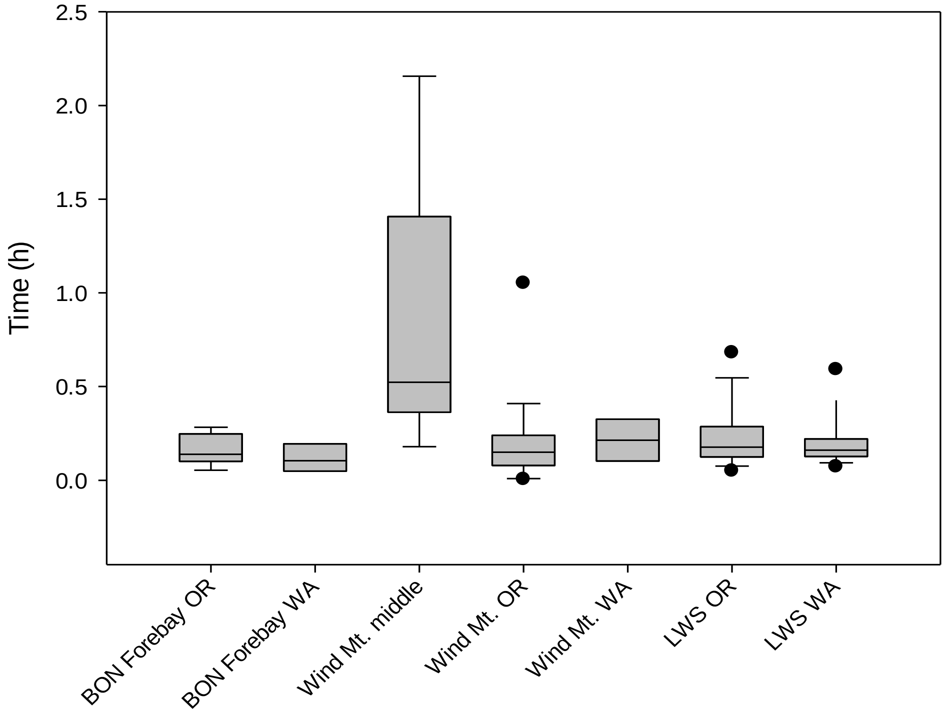

Figure 13. Residence times for JSATS tagged Pacific lamprey on lower Bonneville Reservoir receivers. Sample sizes are shown above each bar. Box plots show 5^{th}, 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles.

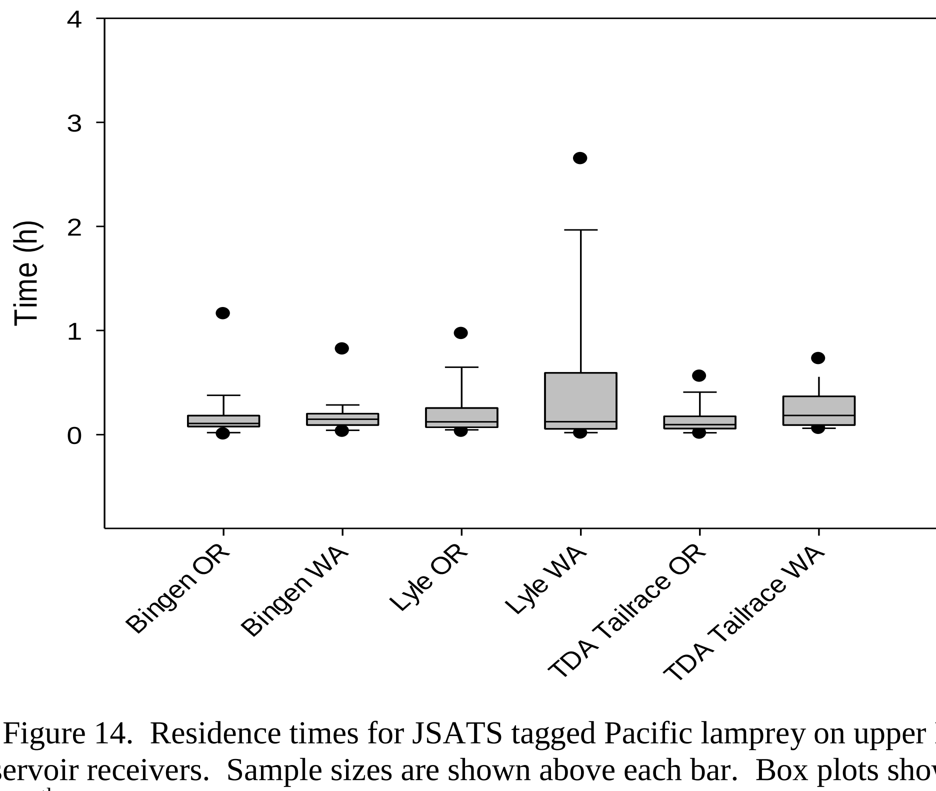

Figure 14. Residence times for JSATS tagged Pacific lamprey on upper Bonneville Reservoir receivers. Sample sizes are shown above each bar. Box plots show 5^{th}, 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles.

Distribution and final fates

The timing of JSATS + HD-PIT tagged and HD-PIT tagged releases to the reservoir differed because HD-PIT releases began before JSATS releases and JSATS releases continued later than HD-PIT only releases. Consequently, we compared the weight and escapement between tag groups in analyses 1) during the period HD-PIT tagged adults were released to the reservoir and 2) the period when both tag types were released. Weight of adults did not differ in either case (Table 3). The probability of passing upstream dams did not differ between adult lampreys double-tagged with JSATS + HD-PIT tags compared to adults tagged with only an HD-PIT tag when comparing all adults released at Stevenson in 2011 (P>0.115; Table 3). Similarly, when we restricted the sample to adults released over the same date range, the probabilities did not differ, except JSATS adults were more likely to pass McNary Dam (though we note the small observed frequencies passing in the McNary comparison breaks the assumptions of the Chi-square test and inflates the probability of falsely rejecting the null hypothesis; Sokal and Rohlf 1995). Logistic regression models that statistically controlled for the effects of tag date and lamprey weight similarly provided no evidence of a tag type effect (P > 0.05).

Table 3. Results of ANOVA comparisons of lamprey weight and Pearson's chi-square tests of upstream dam passage proportions between JSATS and HD-PIT tagged lamprey released at Stevenson, WA. Comparisons were made between two ranges of release dates; 11 June – 3 September (n = 62 JSATS and n = 109 HD-PIT only) and 23 July – 13 August (n = 39 JSATS and n = 97 HD-PIT only).

	Release date 11 June – 3 September			Release date 23 July - 13 August		
	n	F	*P*	*n*	F	*P*
Release date	171	11.7	0.001	136	0.09	0.765
Weight	171	0.1	0.748	136	0.41	0.521
	n	*Chi-square*	*P*	*n*	*Chi-square*	*P*
% past The Dalles	73	0.02	0.880	55	0.09	0.766
% past John Day	45	0.70	0.403	33	2.35	0.126
% past McNary	6	2.49	0.115	4	4.32	0.038

Final records of lampreys from JSATS and HD-PIT antennas were used to estimate the final distribution of lamprey. Less than half (47.8%) of the 23 fish released into the tailrace were detected at or above Bonneville Dam. Eight fish (34.8%) were detected on the Bonneville Dam forebay receiver or above. Seven fish (30.4%) made it as far as the Lyle, WA receivers, and 5 tagged lampreys (21.7%) were detected on The Dalles tailrace receivers. Three fish (13.0%) were detected on the HD-PIT antennas at John Day Dam or above; 2 fish (8.7%) continued to

Priest Rapids Dam and 1 fish (4.3%) was last detected at Wanapum Dam. No tailrace-released fish were recorded entering any monitored tributary, including the Snake River (Table 4).

Once above Bonneville Dam, both release groups showed similar patterns in reach escapement, particularly when passing dams (Figure 15). The tailrace-release group had a distribution pattern similar to reservoir-released fish within Bonneville Reservoir (Figure 15).

Most reservoir-released fish were last detected in the Bonneville Reservoir, including the Bingen, Lyle, and The Dalles Dam tailrace sites (Figure 17). Most of the reservoir-released fish (83.9%, 52/62) were last recorded as far upstream as the Lyle, WA receiver and fewer were last detected as far as The Dalles tailrace (*n* = 42, 67.7%). Fish were also last detected in both of the monitored tributaries; 5 (8%) were last detected on the Klickitat River receiver and 2 (3.2%) were last detected on the Fifteen Mile Creek HD-PIT antennas. While 83.9% of adults were detected at Lyle, less than half (43.5%) were detected at The Dalles HD-PIT antennas or upstream and 34% of adults had last records at Lyle or The Dalles Dam tailrace. Fourteen fish (22.6%) were detected on HD-PIT antennas at John Day Dam or upstream. Five fish (8.1%) were detected at McNary Dam, 2 (3.2%) at Priest Rapids Dam, and 1 fish (1.6%) was detected in the Snake River at Ice Harbor Dam (Table 4).

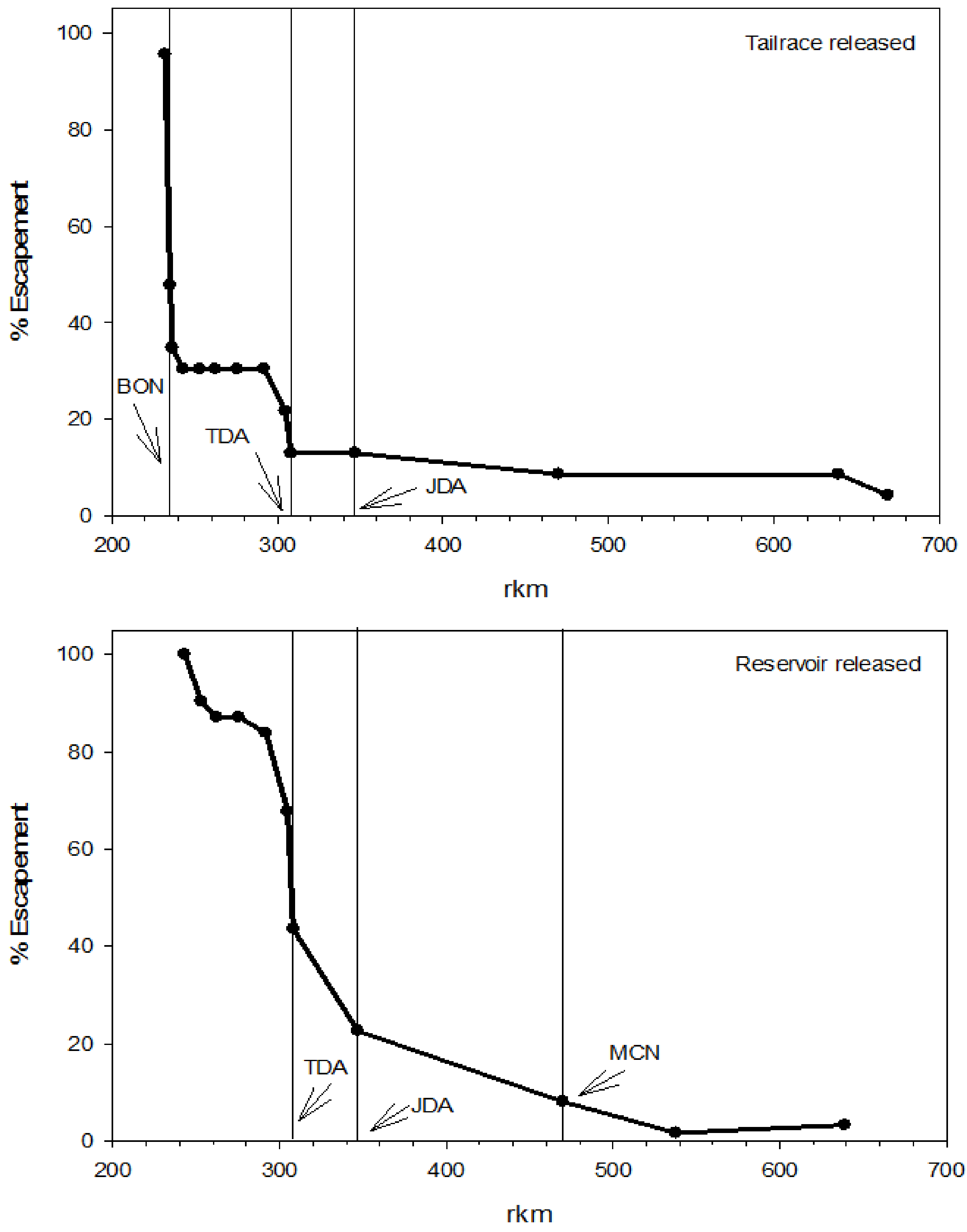

Figure 15. Reach escapement estimates for JSATS-tagged Pacific lamprey for the Bonneville Dam tailrace release group (top) and Bonneville Reservoir release group (bottom). Estimates were made using JSATS and HD-PIT detection records.

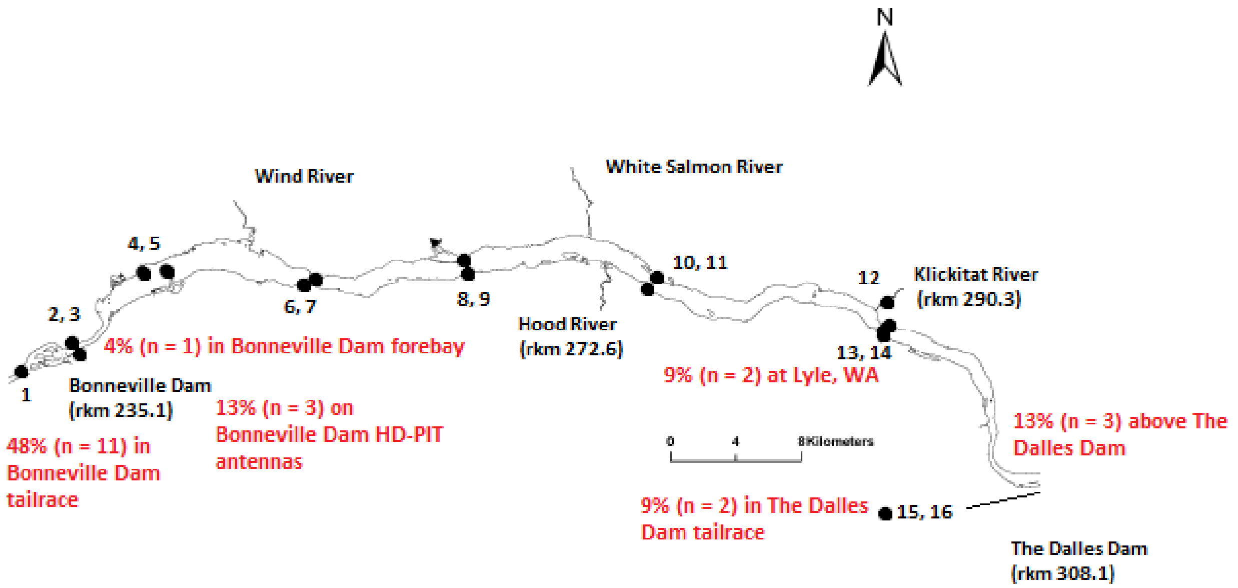

Figure 16. Last detections of JSATS-tagged Pacific lampreys released into the Bonneville Dam tailrace. A single lamprey had no valid detections (not shown).

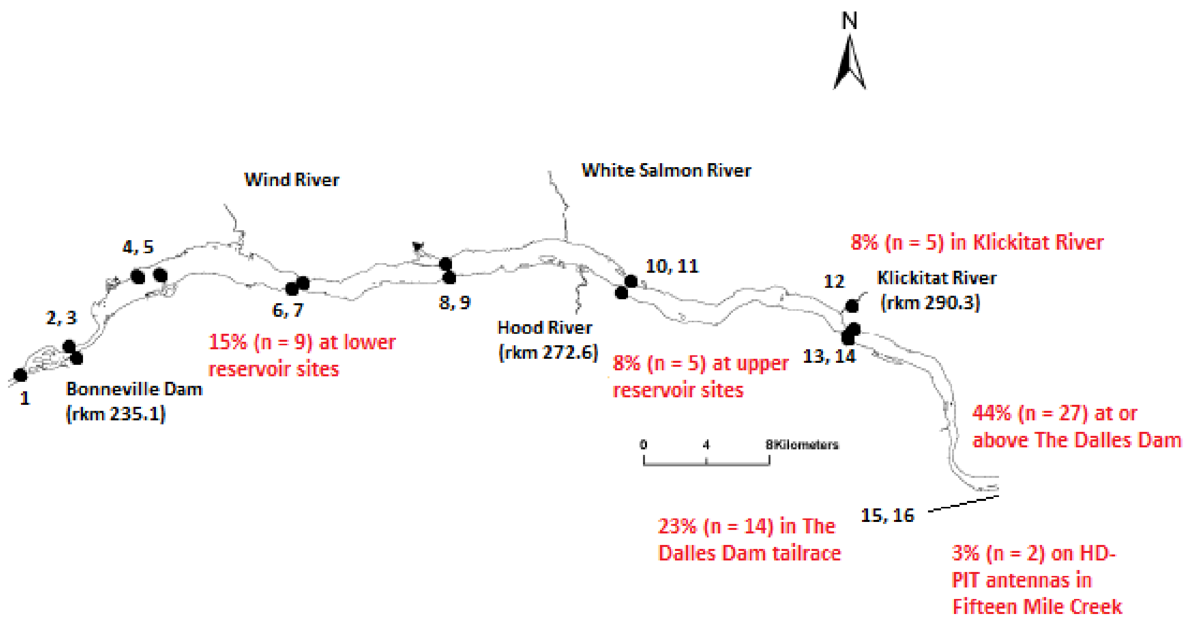

Figure 17. Last detections of JSATS-tagged Pacific lampreys released into Bonneville Reservoir.

Table 4. Escapement estimates by reach for JSATS-tagged Pacific lamprey.

Tailrace (Hamilton Island) release (n=23) Reach	Escapement (%)	Reservoir (Stevenson, WA) release (n=62) Reach	Escapement (%)
Release to Bonneville Dam tailrace	95.7		
Release to Bonneville Dam	47.8		
Release to Bonneville Dam forebay	34.8		
Release to Stevenson, WA	30.4	Release to Stevenson, WA	100
Release to Wind Mt.	30.4	Release to Wind Mt.	90.3
Release to Little White Salmon R.	30.4	Release to Little White Salmon R.	87.1
Release to Bingen, WA	30.4	Release to Bingen, WA	87.1
Release to Klickitat R.	--	Release to Klickitat R.	8.0
Release to Lyle, WA	30.4	Release to Lyle, WA	83.9
Release to The Dalles tailrace	21.7	Release to The Dalles tailrace	67.7
Release to Fifteen Mile Creek	--	Release to Fifteen Mile Creek	3.2
Release to The Dalles Dam inside HD-PIT antennas	13.0	Release to The Dalles Dam inside HD-PIT antennas	41.9
Release to The Dalles Dam top of the ladder HD-PIT antennas	13.0	Release to The Dalles Dam top of the ladder HD-PIT antennas	38.7
Release to John Day Dam	13.0	Release to John Day Dam	22.6
Release to McNary Dam	8.7	Release to McNary Dam	8.1
Release to Ice Harbor Dam	--	Release to Ice Harbor Dam	1.6
Release to Priest Rapids Dam	8.7	Release to Priest Rapids Dam	3.2
Release to Wanapum Dam	4.3	Release to Wanapum Dam	--

Discussion

Past monitoring of adult Pacific lamprey in the Columbia River using radio- and HD-PIT telemetry systems has revealed low dam passage rates, unaccounted losses in Bonneville Reservoir and tailrace, and relatively rapid travel rates through reservoirs compared to passage rates at dams. Radio- and HD-PIT telemetry studies have been unable to determine the final distribution and fate of tagged lamprey that either failed to pass Bonneville Dam or that were last detected entering Bonneville Reservoir. These limitations resulted in part from the inability of radio or HD-PIT technologies to monitor adult Pacific lamprey in deep-water habitats including Columbia River reservoirs and tailraces or through the winter and into the final spring migration and spawning period. In the spring of 2012 we will continue fixed-site monitoring of lampreys tagged with the 400 day JSATS tag in 2011. We expect some lampreys to resume migration in spring, and receivers will be redeployed with an increased emphasis on tributary locations. We will also begin testing of a new JSATS mobile tracking unit with a focus on surveys of the

Bonneville and The Dalles Dam tailraces and upper Bonneville Reservoir in an effort to evaluate habitat relationships and final spatial distributions.

An underlying assumption of telemetry studies is that tagging does not affect behavior or survival. An important element of the 2010 and 2011 JSATS evaluations has been to assess whether JSATS-tagged adult lamprey exhibit evidence of smaller or larger tag effects with respect to available comparison groups (HD-PIT only groups sampled concurrently and radio-only and radio-HD PIT double-tagged groups from previous studies). Past studies have consistently revealed that radio-tags are associated with a decreased probability of dam passage compared to HD-PIT tag groups (e.g., Keefer et al. 2010). We anticipated that the JSATS tag might decrease the magnitude of this effect because the tag is slightly smaller and flatter in profile than radio-tags used in previous studies and because lamprey behavior may be affected by the external antenna and catheter required for radio-tags. Comparing only fish that were detected or released in Bonneville Reservoir, JSATS-tagged fish in 2011 were not as likely (45.7%) to successfully pass The Dalles Dam as radio-tagged lamprey from 2010 (56.9%). However, lamprey dam passage success is negatively correlated with river discharge (Daigle et al. 2008, Keefer et al. 2009b, 2009d), and higher discharge in 2011 than 2010 may have contributed to this pattern. Similarly, body size is consistently positively associated with passage probability (Keefer et al. 2009c) and body size was generally smaller in the 2011 JSATS sample than in the 2010 radiotelemetry sample (Keefer et al. 2011), potentially contributing to the difference in rates between years.

A more direct test of tag effects was the comparison of JSATS + HD-PIT tagged adults vs. the HD-PIT only group in 2011. This comparison found no evidence that the addition of the JSATS tag reduced escapement to upstream sites, though we note that sample sizes were modest. This pattern differs from our past studies that have consistently observed lower escapement in RT + HD-PIT groups compared to HD-PIT only groups (Keefer et al. 2009a, 2009d, 2010). Overall, we provisionally conclude the results support the hypothesis that the JSATS tag had no additional tag effects over the HD-PIT only tagging protocol, noting that sample size was low relative to past studies. Increased sample sizes in 2012 should strengthen this analysis.

Assuming that observed lamprey behavior largely reflected the behavior of the untagged population, the data provide important new observations of Pacific lamprey behavior during migration in the Hydrosystem. In particular, the JSATS technology allowed us to evaluate basic elements of migration behavior within Bonneville Reservoir (passage times and migration rates), monitor for long-distance downstream movements by adults below Bonneville Dam, monitor larger, deeper habitats, and we were able to partition the Bonneville Reservoir into reaches for the estimation of escapement. Results to date indicate that most unaccounted lampreys were last detected in the upper Bonneville Reservoir and tailrace of The Dalles Dam.

Travel times and migration rates

JSATS-tagged lampreys were observed to be migrating faster through comparable reaches than in previously reported studies (Keefer et al. 2009a, 2012; Moser et al. 2004). For example, travel times for JSATS-tagged lamprey from release in the Bonneville Dam tailrace to top of the ladder HD-PIT antennas at Bonneville Dam (*median* = 1.4 d, n = 10), and from Bonneville Dam

ladder top to The Dalles Dam ladder top (*median* = 3.3 d, *n* = 3) were shorter than observed in radio-tagged only lamprey in 2007 (*median* = 7.6 d, *n* = 71, and *median* = 3.8 d, *n* = 19, respectively), although the JSATS-tagged sample sizes are small (Keefer et al. 2009a). However, we only began releasing lampreys into the tailrace in late July when water temperatures were higher and discharge was lower, and there is evidence that these factors may have contributed to faster migration (Moser et al. 2004; Daigle et al. 2008, Keefer et al. 2009b).

JSATS monitoring provided the opportunity to determine migration rates of lampreys within the reservoir without the influence of dam passage time. Within-reservoir travel times and migration rates varied greatly among individuals, were typically rapid, and medians were similar to those observed in the 2010 JSATS study (Naughton et al. 2011).

After release, lamprey appeared to frequently move within reservoirs during daylight hours. Importantly, post-tagging behavioral effects likely influenced the observed diel patterns for the Stevenson WA released adults (the small sample of tailrace-released adults reaching Bonneville Reservoir precluded meaningful examination of diel patterns for this group). In both 2010 (Naughton et al. 2011) and 2011, tagged lamprey were released during daylight hours and were frequently undetected at the release site node until the following night suggesting adults found refuge in benthic habitats until nightfall. Once detected, the relatively short residence times at Stevenson WA-shore (<~2 hours) suggest that once adults commenced movements, they left the release site relatively quickly and rapidly moved upstream. The relatively synchronous movement of adults post-release from the Stevenson release site could have contributed to the observed mid-day and afternoon mode in detections at the Bingen and Lyle gates. Whether the diel mode occurred in the untagged population is unknown. Nonetheless, the results suggest that swimming may be more constant in reservoirs than at dam sites where passage is typically nocturnal, perhaps because light is attenuated in the deeper, less hydraulically complex reservoir habitats than at dams (Keefer et al. 2012). Splitting the 2012 sample of JSATS-tagged lamprey into daytime and nighttime release groups may help determine to what degree the diel patterns resulted from time of release and post-tagging effects.

Distribution and final fates

Determining the fates of lampreys with last records in FCRPS reservoirs was a primary biological objective of this study. Using a combination of JSATS transmitters and HD-PIT tags, we estimated the distributions and final fates of lamprey released to the Bonneville Dam tailrace and Bonneville Reservoir.

Distributions of tagged fish in both release groups (to date) were similar to distributions seen in previous years, though we note that additional data should be available at the end of the 2012 spawning season. The distribution patterns reported in previous years were mostly determined from detections on radio and HD-PIT antennas located at dams, and only showed if a tagged fish approached, entered, exited, or passed a dam. Generally, of the tagged fish observed to successfully migrate past a given dam in past studies, about half were not detected at upstream dams (e.g., Keefer 2009a, 2009d). Little is known from past studies of the final fates of the lampreys last detected entering Bonneville Reservoir, though past radiotelemetry studies indicate that relatively few adults move into spawning tributaries that empty into Bonneville Reservoir in

the fall or early winter (prior to the expiration of radio tag battery life; e.g., Moser et al. 2002; Keefer et al. 2010).

As in past studies, approximately half of the lampreys released downstream from Bonneville Dam were undetected after release. Unlike in previous years, we monitored for a relatively long distance downstream using the PNNL array at rkm 161 and none of the tagged lamprey were detected at that array. It remains unknown whether these adults were prey of sea lions (*Zalophus californicus*, *Eumetopias jubatus*) or white sturgeon (*Acipenser transmontanus*) in the tailrace, moved to spawning tributaries emptying in to the Columbia River between rkm 161 and 232, spawned in mainstem habitats in this same reach, or are holding in this reach prior to final pre-spawn movements in spring 2012. A small number of HD-PIT detections have been observed in spring for adults tagged in prior years at Bonneville Dam suggesting some overwintering in the tailrace. We hope to refine the assignment of fates for the adults failing to pass Bonneville Dam using mobile tracking efforts for adults tagged in both 2011 and 2012.

Monitoring at the mouth of the Klickitat River (JSATS) and in Fifteen-mile Creek revealed final movements of the JSATS adults into these two tributaries. Coverage was limited to these tributaries and to what degree movements into tributaries in spring 2012 and movement into other unmonitored tributaries accounts for lampreys last observed in Bonneville and other reservoirs remains unresolved. Past radiotelemetry studies suggest movements into the Klickitat River and 15-mile Creek are more common than to other Bonneville Reservoir tributaries during late summer and fall (Keefer et al. 2010). Tributary monitoring, including testing and deployment of the new mobile tracking unit (Advanced Telemetry Systems, Kraken ST6000) will be the focus of coverage in spring 2012, a time period that we have been unable to monitor effectively in past studies. JSATS telemetry monitoring is ongoing and spring movements of tagged lampreys are expected and both improved JSATS and HD-PIT monitoring of tributaries in future years should improve these estimates.

A key finding of this study is the observation that the vast majority (84%) of adults entering or released to Bonneville Reservoir rapidly and successfully passed ~80% the length of the reservoir and were detected at the Lyle gate, approximately 16 rkm below The Dalles Dam. This suggests that migration conditions and factors such as predation are not strongly contributing to the overall unaccounted losses in the Bonneville Reservoir during the summer and fall migration, and that fish are not overwintering in the downstream two-thirds of Bonneville Reservoir. Refining the final distribution and fate of this group will be a focus of early 2012 monitoring and the 2012 JSATS study. Potential mechanisms include: 1) Lampreys are overwintering in The Dalles Dam tailrace and resuming upstream migration in the spring, 2) Lampreys are overwintering in The Dalles Dam tailrace and returning to downstream spawning tributaries in the spring, 3) Lampreys are spawning in The Dalles Dam tailrace in the spring, 4) adults with final records at Lyle and The Dalles Dam tailrace were prespawn mortalities or predation mortalities. Previous HD-PIT studies show little evidence that fish undertake long upstream movements in the main stem in the spring following tagging, and the high percentages of fish reaching upper Bonneville Reservoir sites suggest that prespawn and predation mortality in the lower reservoir accounts for few missing fish, at least during fall. Fixed receiver sites at Bingen, Lyle, or in The Dalles tailrace should detect any downstream movements of any tagged lamprey that overwintered in The Dalles Dam tailrace and moved downstream to spawning tributaries in the spring and summer of 2012. Fixed receiver sites in and around the mouths of tributaries

should detect entry of tagged fish and intensive mobile tracking efforts in the spring and summer of 2012 should reveal fine-scale habitat use by lamprey in the tailrace environment.

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